The effect of giant molecular clouds on star clusters

M. Gieles[1,2], S.F. Portegies Zwart[2], and E. Athanassoula[3]

[1] Utrecht University gieles@astro.uu.nl
[2] University of Amsterdam spz@science.uva.nl
[3] Observatoire de Marseille lia@oamp.fr

1 When a star cluster meets a cloud

We study the encounters between stars clusters and giant molecular clouds (GMCs) [3]. The effect of these encounters has previously been studied analytically for two cases: 1) head-on encounters, for which the cluster moves through the centre of the GMC [1] and 2) distant encounters, where the encounter distance $p > 3R_{\rm n}$, with p the encounter parameter and $R_{\rm n}$ the radius of the GMC [6]. We introduce an expression for the energy gain of the cluster due to GMC encounters valid for all values of p and $R_{\rm n}$ of the form

$$\Delta E \simeq \frac{4.4\, r_{\rm h}^2}{\left(p^2 + \sqrt{r_{\rm h}\, R_{\rm n}{}^3}\right)^2} \left(\frac{GM_{\rm n}}{V_{\rm max}}\right)^2 M_c. \tag{1}$$

Here $V_{\rm max}$ is the maximum relative velocity, $M_{\rm n}$ is the mass of the GMC, G is the gravitational constant and $r_{\rm h}$ and $M_{\rm c}$ are the half-mass radius and mass of the cluster, respectively. We perform N-body simulations of encounters with different p and compare the resulting ΔE of the cluster to Eq. 1. Fig. 1 shows the very good agreement between simulations and predictions of Eq. 1. Snapshots of one simulation are shown in Fig. 2.

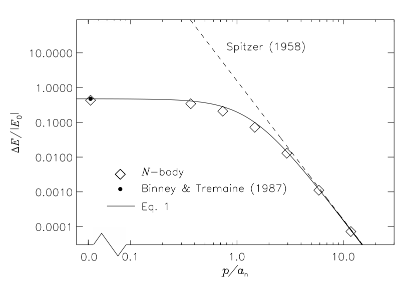

Fig. 1. $\Delta E/|E_0|$ of a cluster as a function of p. The N-body results are shown with diamonds. The result of [1] and [6] for head-on and distant encounters are shown as a filled circle and as a dashed line, respectively. Eq. 1 is shown as a full line.

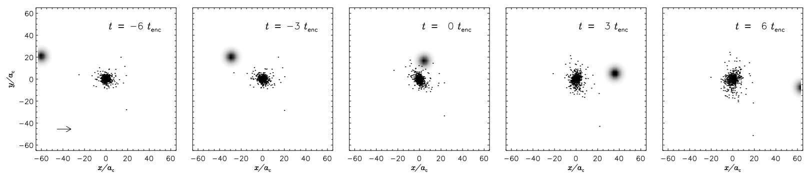

Fig. 2. Simulation of a close encounter between a GMC (grey shades) and a star cluster. The snapshots are viewed in the centre-of-mass frame of the cluster. a_{c} is the Plummer radius of the cluster.

2 The cluster disruption time

From the simulations we find that the fractional mass loss ($\Delta M/|M_0|$) is only 25% of $\Delta E/|E_0|$. This is because stars escape with velocities much higher than the escape velocity. Defining the cluster disruption time as $t_{\mathrm{dis}} = M_{\mathrm{c}}/\dot{M}_{\mathrm{c}}$, we find a cluster disruption time of the form

$$t_{\mathrm{dis}} = 2.0\, S \left(M_{\mathrm{c}}/10^4\, M_{\odot}\right)^{\gamma} \mathrm{Gyr}, \qquad (2)$$

with $S \equiv 1$ for the solar neighbourhood and scales with the global GMC density (ρ_{n}) as $S \propto {\rho_{\mathrm{n}}}^{-1}$. The index γ is defined as $\gamma = 1 - 3\lambda$, with λ the index that relates the cluster half-mass radius to its mass ($r_{\mathrm{h}} \propto {M_{\mathrm{c}}}^{\lambda}$). The observed shallow relation between cluster radius and mass (e.g. $\lambda \simeq 0.1$), makes the index ($\gamma = 0.7$) similar to the index found both from observations [4] and from simulations of clusters dissolving in tidal fields ($\gamma \simeq 0.62$). The constant of 2.0 Gyr, which is the disruption time of a $10^4\, M_{\odot}$ cluster in the solar neighbourhood, is about a factor of 3.5 shorter than found from earlier simulations of clusters dissolving under the combined effect of the galactic tidal field and stellar evolution. It is only slightly higher than the observationally determined value of 1.3 Gyr [4], suggesting that the combined effect of tidal field and encounters with GMCs can explain the lack of old open clusters in the solar neighbourhood [5]. GMC encounters can also explain the (very) short disruption time that was observed for star clusters in the central region of M51 [2], since there ρ_{n} is an order of magnitude higher than in the solar neighbourhood.

References

1. J. Binney & S. Tremaine, Galactic dynamics (1987)
2. M. Gieles, N. Bastian, H.J.G.L.M. Lamers, & J.N. Mout, A&A **441**, 949 (2005)
3. M. Gieles, S.F. Portegies Zwart, H. Baumgardt, E. Athanassoula, H.J.G.L.M. Lamers, et al., MNRAS, submitted (2006)
4. H.J.G.L.M. Lamers, M. Gieles, N. Bastian, et al., A&A **441**, 117 (2005)
5. J.H. Oort, Ricerche Astronomiche, **5**, 507 (1958)
6. L.J. Spitzer, ApJ **127**, 17 (1958)